ELECTROWEAK PHYSICS AT LEP2

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The measurements resulting from the analysis of the LEP2 data have brought more strong evidence in support of the standard electroweak model. In particular the LEP2 data has revealed (i) the first determination of the SU(2) gauge bosons self-couplings, (ii) the first direct measurements of the W decay-couplings, and (iii) the current best direct measurement of the W mass.

1. Introduction

During the LEP2 program a total of about 3 fb^{-1} of e$^+$e$^-$ data at centre-of-mass energies $\sqrt{s}$=161-209 GeV, have been collected. A selection of Standard Model (SM) electroweak measurements established with this data is given in the following.

2. Single Photons and Photon Pairs

Single photon final states arise at LEP2 from the e$^+$e$^- \to$ Z$\gamma \to \nu\overline{\nu}\gamma$ process. The missing mass distribution in single photon events selected at LEP2 energies is shown in Fig. 1, and clearly shows the Z mass peak decaying into neutrino pairs. The analysis of these events provides a direct measurement of the Z decay rate to neutrinos, and from this the number of light neutrino families is derived to be $N_\nu = 2.84 \pm 0.08$, in good agreement with the more precise indirect determination from the LEP1 Z width measurements, $N_\nu = 2.984 \pm 0.008$[1].

Photon pair productions provide a test of the purely QED process e$^+$e$^- \to \gamma\gamma$. As can be seen in Fig. 1, the measured LEP2 cross-sections agree nicely with the QED predictions at the percent level.

Both results on single photon and photon-pair productions at LEP2 can be used to extract limits on the scale of many new physics models beyond the Standard Model, up to the TeV level[2].
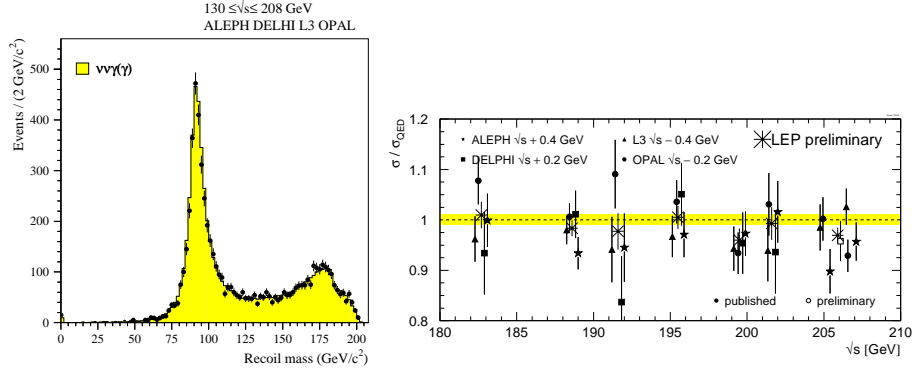
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Figure 1.   Distribution of the recoil mass in single photon events from all LEP2 data (left). Ratios of measured cross-section over QED predictions for photon-pair production at different LEP2 energies. The shaded area represents the theoretical uncertainty (right).

3. Fermion Pairs

Fermion pairs with $q\overline{q}$, $\mu^+\mu^-$ and $\tau^+\tau^-$ final states are produced in e^+e^- collisions with a γ/Z s-channel exchange. The total cross-sections and forward-backward asymmetries measured at LEP2 energies are in agreement with the electroweak predictions for γ/Z interference at the percent level. Bhabha $e^+e^- \rightarrow e^+e^-$ final states get additional large contributions from the t-channel γ exchange, for forward angle scattering. Also in the Bhabha channel the LEP2 measured total and differential cross-sections are in nice agreement with electroweak predictions at the 1-10% precision level, according to the scattering angle[2].

Just like for photons, also fermion pair final states have been analyzed to extract limits on the scale of different physics models beyond the Standard Model, up to the TeV level[2].

4. Single W and Z

Single electroweak boson productions $e^+e^- \rightarrow We\nu$ and $e^+e^- \rightarrow Zee$ represent four-fermion final states. The luminosity weighted cross-section averages for these processes, at the LEP2 average centre-of-mass energy of $\sqrt{s} \simeq 198$ GeV, are $\sigma(e^+e^- \rightarrow We\nu) = 0.77 \pm 0.05$ pb for single W production, and $\sigma(e^+e^- \rightarrow Zee \rightarrow qqee) = 0.55 \pm 0.03$ pb for single Z production. Both measurements are in agreement with the SM expectations at 7% and 5% precision level[2].

5. W and Z Pairs

W-pair production is one of the most interesting processes of the electroweak model, where the non-abelian structure of the SU(2) group leads to the presence of gauge boson self couplings that play a crucial rôle establishing the gauge cancellations that guarantee the W-pair process unitarity and the renormalizability of the theory.

Results for the W-pair cross-sections as a function of the LEP2 energy[2] are shown in Fig. 2, and are in agreement with the SM expectations at the 1% level. The measured W-pair production rates represent the first clear proof of the presence of both the WWγ and WWZ couplings dictated by the SU(2)$\otimes$U(1) gauge structure.

Results for LEP2 Z-pair cross-sections are also shown in Fig. 2 where the agreement with the SM expectations is at the level of 5%. In this case the Z-pair data rules out the presence of purely neutral gauge self couplings, such as ZZγ and ZZZ vertices, that are not predicted by the electroweak theory.
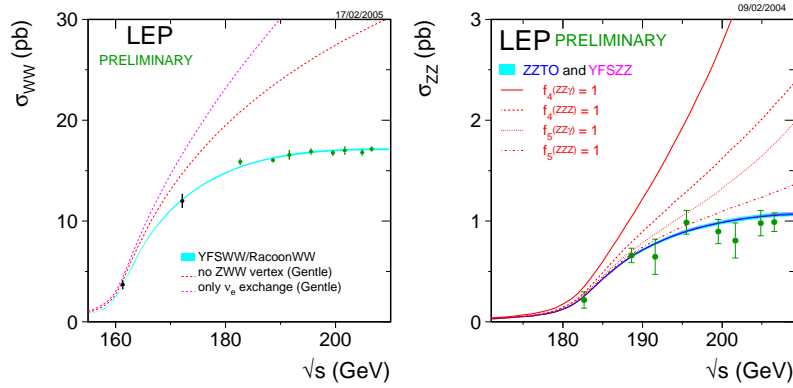

Figure 2. Combined LEP results for production cross-sections for W-pairs (left) and Z-pairs (right), as a function of the centre-of-mass energy. The lower shaded curves represent the Standard Model predictions and uncertainties. The upper curves on the W-pair production plot show the predictions in the absence of the γWW and ZWW couplings. The upper curves on the Z-pair production plot show the predictions in the presence of different possible ZZγ and ZZZ couplings.

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6. Gauge bosons self-couplings

The structure and magnitude of the γWW and ZWW couplings are extracted from the W-pair event rates and angular distributions[2]. A fit with the ALEPH data[3] to the 28 parameters of the most general Lorentz-invariant vertex structures leads to results in agreement with the SU(2)$\otimes$U(1) predictions with precisions of 3-20%, according to the measured parameter.

A more constrained fit of all LEP2 data, in search of anomalous contributions in gauge couplings, to the three couplings that conserve separately C and P, U(1)$_{\mathrm{em}}$, and global SU(2)$\otimes$U(1), yields[2] $\kappa_\gamma = 0.984 \pm 0.045$, $\lambda_\gamma = -0.016 \pm 0.022$, and $g_1^Z = 0.991 \pm 0.021$, revealing again no deviation from the SM expectations.

7. W decay couplings

The LEP2 W-pair sample has allowed the first direct measurements of all hadronic and leptonic W decay branching ratios to be B(W $\rightarrow$ eν) = $10.69 \pm 0.17\%$, B(W $\rightarrow \mu\nu$) = $10.57 \pm 0.16\%$, B(W $\rightarrow \tau\nu$) = $11.39 \pm 0.23\%$, and B(W $\rightarrow$ qq) = $67.51 \pm 0.29\%$. These results insure the lepton-quark universality of charged currents at the 0.6% level ($g_\mathrm{q}/g_\ell = 1.000 \pm 0.006$), and of the lepton family universality of charged currents at the 1% level. However, the tau coupling to the W appears to be 2.6 standard deviations larger than the combined electron and muon couplings as $2g_\tau/(g_\mathrm{e} + g_\mu) = 1.036 \pm 0.014$.

The W hadronic decay fraction can also be interpreted as a test of the unitarity of the CKM quark mixing matrix in the first two families, as $\sum |V_{ij}| (i = u, c; \ j = d, s, b) = 2.000 \pm 0.026$, and from this extract the Wcs coupling amplitude $|V_{cs}| = 0.976 \pm 0.014$, without CKM unitarity assumptions.

8. W boson mass and width

The first LEP2 W mass determination has been extracted from the W-pair production threshold cross-section[2] yielding $m_\mathrm{W} = 80.40 \pm 0.20$ GeV/c^2. For the direct measurement, the W invariant mass is reconstructed event-by-event in all qqqq and qq$\ell\nu$ decays of W-pairs, from the kinematics of the visible decay particles, and the resolution of the W mass peak is improved by applying a kinematic fit imposing energy-momentum conservation constraints from the LEP2 energy. The W mass and width values can be extracted from the W mass data distributions using different fit methods, and

yielding $m_W = 80.412 \pm 0.042$ GeV$/c^2$, and $\Gamma_W = 2.150 \pm 0.091$ GeV$/c^2$, where the weight of the fully hadronic (qqqq) channel is only 10% because of large uncertainties coming from possible final state interactions effects between the two W hadronic decay products. The inclusion of the current W mass determinations in the electroweak fit yields a constraint on the SM higgs mass $114 < m_h < 260$GeV$/c^2$ at 95% confidence level[2].
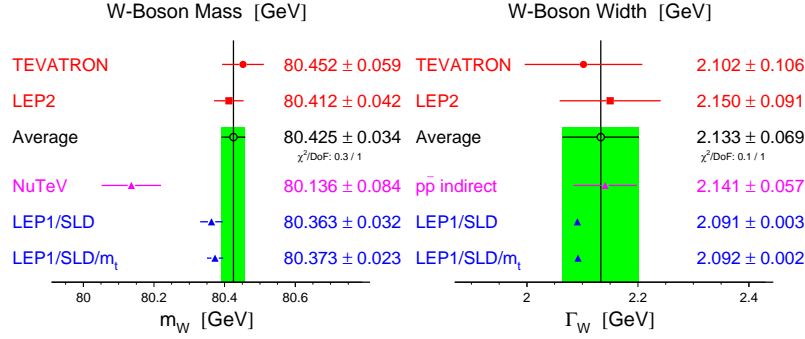

Figure 3.   Summary of W mass and width measurements. Direct measurements from LEP2 and the TEVATRON are shown on the top, indirect constraints from other electroweak determinations on the bottom.

Acknowledgments

References

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